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(54) Inductively coupled load monitoring of rotating shaft

(57) An apparatus for monitoring a load on a rotating shaft includes a strain gauge bridge (22) attachable to the shaft and inductive transmission means (18, 19) connected respectively to a stationary part and the rotating shaft for both transmitting power to and signals from the transducer at different carrier frequencies separable by filtering; a stationary decoding circuit 30 giving a voltage output.

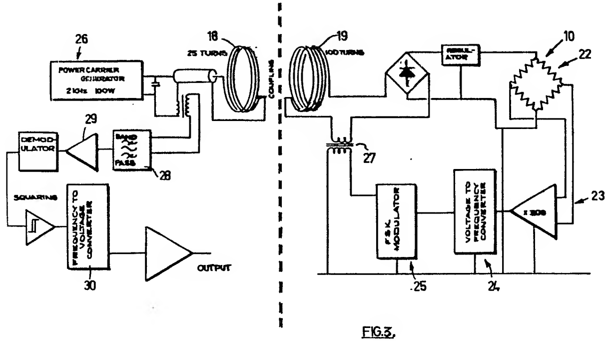

FIG.3.

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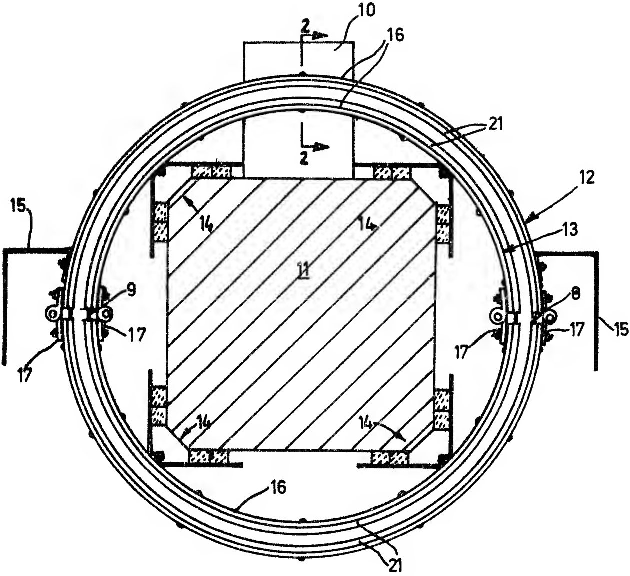

FIG.1.

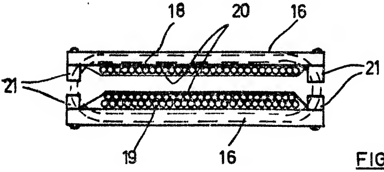

FIG.2.

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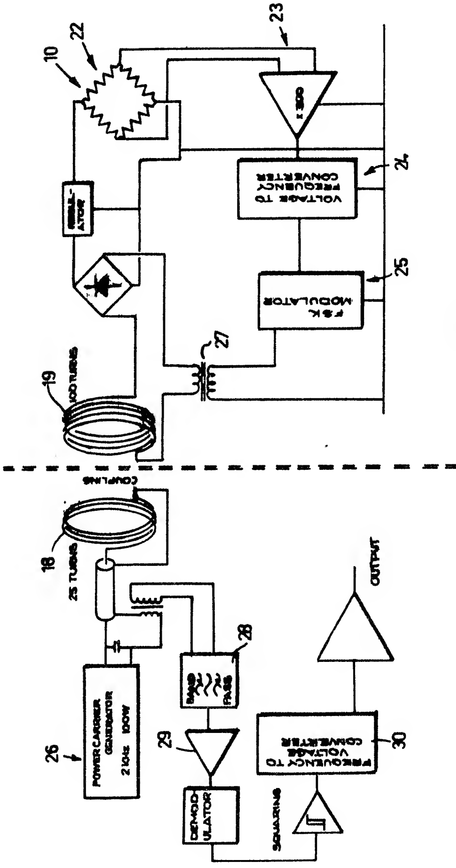

FIG.3.

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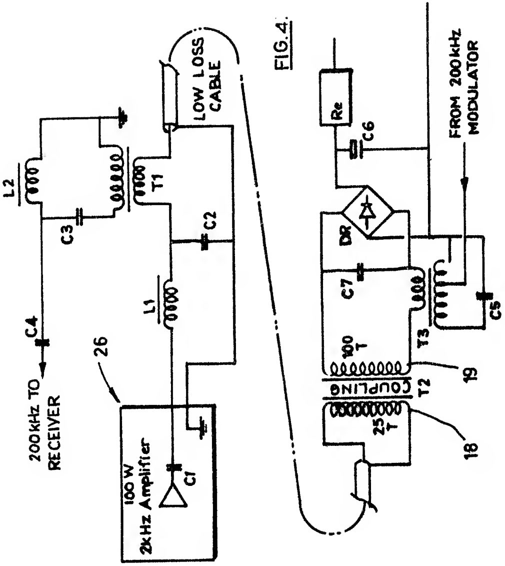
FIG. 4.
LOW LOSS CABLE
L2
T1
C3
C2
L1
C4
200kHz TO RECEIVER
26
100 W 2kHz Amplifier
C1
Re
C6
FROM 200kHz MODULATOR
DR
C7
C5
T3
100 T
COUPLING
T2
19
25 T
18

SPECIFICATION

Load monitoring means

This invention relates to an improved method of and means for monitoring an effect on a moving member such as a rotating shaft.

In heavy machinery it is often desirable to monitor the torque transmitted by a drive shaft in order to provide warning of an overload condition or simply to optimise machine performance.

Frequently a drive shaft is coupled to operational means and the shaft torque will vary in accordance with the load imposed upon the operational means. In sugar mills for example, the torque transmitted by the drive shaft for the crushing mill may vary in accordance with the mill feed rate and the variation of pressure in the chest of the turbine which powers the mill. At present the turbine chest pressure is monitored in order to regulate the feed rate and thus limit the maximum load which may be imposed upon the mill apparatus. The monitoring means utilized frequently operate in harsh environment in which most presently available electronic monitoring equipment will not operate reliably. For example the use of slip-rings to obtain reliable electrical signals from strain gauges mounted on rotating shafts is not feasible. This may be overcome by the use of suitable telemetry means, however the telemetry apparatus available to date is both very costly and is not particularly adapted for use in such harsh environments.

It is an object of the present invention to provide a method of and means for monitoring effects such as strain imposed on moving components which will alleviate the above mentioned disadvantages. Other objects and advantages of the present invention will hereinafter become apparent.

With the foregoing and other objects in view, this invention in one aspect resides broadly in a method of monitoring an effect on a mechanical component, the method comprising providing a contactless electrical coupling between monitoring means mounted on said component and a remote decoding assembly and transmitting electrical signals from said monitoring means to said decoding assembly through said coupling. The contactless electrical coupling may be by way of a capacitive or an electro-magnetic coupling but preferably it is an inductive coupling. Suitably the electrical power supply for the monitoring means is also transmitted through a contactless electrical coupling, but of course the monitoring means could be battery powered if desired.

In a preferred form, the power supply and the signal are transmitted through a common inductive coupling. In such instance the frequency of the power supply transmission carrier and the frequency of the return signal transmission are numerically spaced apart whereby a receiving means may utilize a filter assembly to separate the power supply transmission from the signal transmission. For this purpose the power carrier is preferably generated in such form that minimum harmonics are present in order that the filtering of the return signal transmission may be simplified. The frequency of the power supply signal may be in the lower spectrum of the audible range while the frequency of the signal transmission may be in the radio frequency range. Preferably the power supply signal frequency is in the lower audible range whereby it will cause minimum interference to radio signals and whereby it can be easily monitored by earphones or the like. The signal transmission frequency is suitably in the range 150 kHz to 250 kHz.

In accordance with another aspect, this invention resides in shaft load monitoring apparatus including, load monitoring means adapted to be mounted on a shaft and to provide an electrical output proportional to or predictably variable with respect to monitored shaft load; inductive coupling means for transferring said electrical output from said shaft and including a first coil assembly adapted for mounting on said shaft and a coupling coil assembly adapted to be supported adjacent said first coil assembly; decoding assembly associated with said inductive coupling means and load indicator means, said decoding assembly being adapted to decode said electrical output from said inductive coupling means for controlling said load indicator means.

The indicator means may be in the form of a gauge or digital readout means or it may be in the form of a controller for controlling loadings on said member. The decoding means may be shaft mounted if desired but preferably it is mounted remote from the shaft and connected to said coupling means. The monitoring means may be a transducer.

Suitably the monitoring means is a strain-gauge bridge. The latter may be powered from a remote source of electrical energy transmitted inductively to the rotatable member. The inductive coupling means for the powder and or transmission signals may include a pair of coils formed on radially spaced concentrically disposed formers each including a pair of complementary semicylindrical parts. The former parts may be made of conductive material with the respective parts electrically isolated from one another. Each coil may be formed from a small number of windings of ribbon type cable having a plurality of conductive paths therethrough with the ends of the respective paths being interconnected to form a coil of appropriate number of turns. The output from the strain-gauge bridge may be amplified and modulated for transmittal via the inductive coupling and the receiving means may include filter means and or a demodulator means.

In yet a further aspect this invention resides broadly in an inductive coupling for transmitting electrical signals between a stationary member and a rotatable shaft, including a first former assembly adapted to be supported concentrically about the shaft; a coil assembly wound about said first former; a second former adapted to be supported concentrically and in radially spaced relationship to said first former and a coil

assembly wound about said second former. The transmission may be for electricity power supply.

In order that the present invention may be more readily understood and put into practical effect, reference will now be made to the accompanying drawings which illustrate a typical application embodying the present invention for monitoring shaft load, wherein:—

FIG. 1 is an end view illustrating the mounting of inductive coupling coils onto a rotatable shaft and a fixed mounting;

FIG. 2 is an enlarged cross-sectional view of the primary and second windings of the inductive coupling coils, taken along the line 2—2 of FIG. 1;

FIGS. 3 and 4 are electrical block schematics illustrating the present invention.

As illustrated in FIG. 1 an inductive coupling between monitoring means 10 mounted on a shaft 11 and a remote decoding assembly is achieved by locating radially spaced coil assemblies 12 and 13 concentrically about the rotatable shaft 11. The inner coil assembly 13 is fixed to the shaft by resilient mounting means 14 at each corner of the square sectioned drive shaft 11 and the outer coil assembly 12 is fixedly located by mounting brackets 15 supported on a fixed part of the machine. Each coil assembly 12 and 13 includes a pair of semi-cylindrical mild steel formers 16 the respective pairs of which are connected together by nylon hinges 17 so as to form cylindrical formers which do not provide an electrically continuous loop around the shaft 11. The insulating hinges 17 are used since the formers 16 must not act electrically as shorted turns in the inductive coupling assembly. Additionally by hinging the former pairs they may be placed in their operative position without removal of the shaft.

As can be seen in FIG. 2, the windings 18 and 19 are formed onto the respective coupled steel formers 16.

The inner coils or windings 19 formed in the coil assembly 13 encircle the shaft 11 and the number of turns in this embodiment is approximately 100. The installation would be cumbersome if plain winding wire were employed. A relatively convenient method of making the windings is by the use of ribbon cable. Fifty-way cable is looped around the shaft and the two ends joined together by printed-circuit edge-type connectors in such a way that the end of each conductor in the loop is connected to the start of the adjacent conductor in the next loop. Thus, the apparently parallel conductors perform electrically as a spiral wound coil. The ribbon cable is laid flat on the faces of the steel ring formers 16 and covered with a protective sheet of polyethylene 20 extending between annular end strips 21.

Referring to FIGS. 3 and 4 it will be seen that the monitoring means 10 which is mounted on the shaft 11 includes a bridge network of strain gauges 22, signal amplification means 23, a voltage to frequency convertor 24 and a modulator 25 operating in this instance between 190 and 200 kHz. Power to drive the strain gauges 22 and associated electronic equipment on the shaft is supplied from an amplifier 26 providing in this instance a 2 kHz 100 watt sinewave power supply.

The inductive coupling circuit is illustrated in FIG. 4. In this circuit the main signal current path is from the 200 kHz output, through the primary of transformer T3 and series injection is effected into the loop formed by the secondary of transformer T3, capacitor C7 and the 100 turn coupling coil of the coupling T2. The current is then coupled across the flux path of transformer T2, through the primary of transformer T1 and returns through capacitor C2. Coupled from the primary coil of transformer T1 to secondary coil, the signal is selected by resonant circuits and passed through capacitors C3 and C4 to the receiver amplifier. The power current path is from the 2 kHz generator, through capacitor C1, and inductor L1, the primary coil of transformer T1, the heavy gauge co-axial cable (the current here is approximately 5A peak to peak), then through the fixed coupling coil of the coupling T2 and returning to common. After coupling through the coupling T2 the power current passes through the small winding of transformer T3 and is rectified by the bridge DR and smoothed by capacitor C6. It is then regulated to 10V by a precision regulator Re. The power supply provides enough current to energise the strain gauge bridge 22 and associated equipment on the shaft.

Referring to FIG. 3, the signal voltage after amplification by the amplifier 23, is converted to frequency in the circuitry 24 wherefrom a digital square wave output is available, its frequency being proportional to the strain signal. This frequency modulated waveform is used to switch the input to a single-chip Frequency-Shift-Keyed (FSK) sinewave generator 25 which is normally used in data modems, but here it serves as a signal carrier generator. It generates a VLF (very low frequency) sinewave whose frequency changes from 200 kHz to 190 kHz and back again as the input square wave switches between its low and high state. This double frequency-modulated carrier current is injected into the coupling loop via a small transformer 27 (identified as T3 on FIG. 5). The very low frequency frequency-modulated carrier flows in the 100 turns of the inner coupling loop 19 and induces similar but much smaller currents in the larger, fixed loop 18.

The VLF signal is received and demodulated by the fixed circuitry which is normally situated in a control room and connected to the fixed (outer) coupling loop 18 by a co-axial cable. The same cable carries both the VLF FM signal and the 2 kHz power supply current. The power supply current typically has a peak-to-peak amplitude of five amperes and 40 volts, and the co-axial conductor therefore has to have adequate cross-section. After filtering by a suitable band pass filter 28 the retrieved VLF signal is amplified by the amplifier 29 and applied to the demodulator 31 producing at its output a square wave that is frequency

modulated by the strain signal. This waveform is passed through a squaring circuit 32 to a demodulator 30, used here as a frequency-to-voltage converter.

The output signal closely approximates the strain variations in the shaft 11. Significant transient variations are often present and if the signal is to be used for control purposes these rapid fluctuations have to be smoothed out. A second output for overload protection can also be provided whereby the level of strain at which alarm is given can be pre-set.

Suitably the strain gauge amplifier and the transmitter circuitry are housed in a waterproof box mounted on the shaft being monitored. The telemetry system described above has been designed so as to make it suitable for use, adjustment and maintenance within a sugar mill. In such applications its performance has to be adequate for control purposes, its removal from and installation on an existing shaft easy, and its performance unaffected by dust, steam, water hoses and temperature variations. All the electronic components used in the system described, are readily available general purpose devices. They are simple basic function blocks which will be easy to replace with substitutes, should the original types become obsolete.

Inductive coupling between adjacent coils of wire is chosen in the illustrated embodiment as the means of contactless electrical or wireless transmission, and various compromises may be made regarding the number of turns, the spacing between the coils and the frequencies of the alternating currents (the carrier frequencies). The greater the gap between the coils, the poorer the magnetic coupling and therefore the gap must be as small as possible, yet without mechanical interference between the rotating and the fixed parts of the assembly. A gap between the coils of 25 mm is suitable. The higher the carrier frequency the better the coupling, however, the power and frequency of the carriers should not produce appreciable interference to the communication, navigation and broadcast spectrum. At the same time, the power carrier frequency has to be very different from the signal carrier in order to simplify filtering at the receiver. The power frequency, therefore, is desirably as low as possible, yet maintaining adequate supply for the strain gauge amplifier. At a frequency of 2 kHz approximately 1.5 watts can be transferred through the inductive coupling by conventional and readily available drive circuitry. Audio amplifiers with a nominal 100 watt output capability at 2 kHz are commonplace in public address and entertainment systems. The FSK FM signal carrier frequency and amplitude is as low as possible in order to minimize chances of radio spectrum interference.

Approximately 200 kHz is a satisfactory frequency for the FM carrier. Simple filtering arrangements enable this carrier to be retrieved from the power carrier of much greater amplitude. Only 100 milliwatts are required for adequate coupling. With the external shielding provided by the outer ring of the coupling, this signal is so weak on the outside of the coupling as to be undetectable only a few metres from the shaft 11. Care has been taken to minimize the introduction of harmonics into both the power and the signal carriers, in order to simplify the filtering and to reduce the possibility of radiating interference. Frequency modulation for signal transmission is chosen since it is an effective way to transmit analogue information via a non-contact path. The range of modulation is preferably within the audio range in order that a simple earpiece may be used for testing and fault finding. With the modulation arrangements chosen here, a simple transistor radio can be modified to become a valuable, yet cheap, service tool. The signal carrier is keyed between 190 and 200 kHz. A broadcast receiver, modified to receive 200 kHz is unable to receive the signal during 190 kHz phases. The amplitude-detected output therefore appears as an audio frequency square wave, well suited to reproduction by the loudspeaker. The pitch of the resulting tone varies with tailbar torque. High pitch is given at low torque, low pitch at high torque. As a quick and convincing fault finding aid, this method of tracing signals may be very valuable.

The magnetic coupling can be regarded as a loosely coupled transformer, with the magnetic flux encircling the windings as shown in FIG. 2. The mild steel ring formers assist the coupling but the material is far from ideal as audio and VLF transformer core, and considerable losses occur. The overall transformer efficiency is only 1.5 percent. In view of the low price and easy of fabrication of the mild steel rings, this construction is still acceptable but of course other materials may be used if desired.

The mechanical component in which the load is monitored may be a rotating shaft as per the described embodiment and of course the shaft being monitored could be a propellor shaft in a large ship or a small drive shaft in a vehicle or mechanism. Furthermore the load being monitored may be torque applied by a torsion spring or the like. In the application of the invention to rotary shafts, the rotary speed may also be monitored to enable the torque and speed to be compared to provide a power output. This invention may be utilized also in applications for monitoring loads on rotating or stationary components where substantial electrical isolation is required between the component and earth.

It will of course be realised that the effects which may be monitored include for example, strain, force, displacement or deflection or pressure/vacuum, suitable sensing means being utilized as desired. The illustrated embodiment has been given by way of example only and all such modifications and variations to the invention as would be apparent to persons skilled in the art are

deemed to fall within the broad scope and ambit of the present invention as is defined in the appended claims.

CLAIMS

1. A method of monitoring effects on a mechanical component, the method comprising providing a contactless electrical coupling between monitoring means mounted on said component and a remote decoding assembly and transmitting electrical signals from said monitoring means to said decoding assembly through said coupling.

2. A method of monitoring effects according to claim 1, wherein said contactless electrical coupling is an inductive coupling.

3. A method of monitoring effects according to claim 1 or 2, the method further comprising transmitting electrical power to drive said monitoring means from a remote power source through said coupling.

4. A method of monitoring effects according to claim 3, including transmitting the electrical power transmission and the signal transmission at different frequencies.

5. A method of monitoring effects according to claim 4, including transmitting the electrical power transmission at a frequency in the lower spectrum of the audible range and transmitting the signal transmission in the radio frequency range.

6. A method of monitoring effects according to claim 4 or 5, including converting said electrical signal from said monitoring means to a square wave having a frequency proportional to the detected effect and using the square wave to switch a frequency shift keyed sinewave generator to form a very low frequency sinewave carrier signal.

7. A method of monitoring effects on a mechanical component according to any one of claims 2 to 6 and wherein said mechanical component is a shaft rotatable about its longitudinal axis, the method including forming said inductive coupling by arranging a first coupling coil concentrically about said axis and supporting a complementary coupling coil concentrically about said axis and radially spaced from said first coupling coil.

8. Shaft load monitoring apparatus including, load monitoring means adapted to be mounted on a shaft to be monitored and to provide an electrical output proportional to or predictably variable with respect to monitored shaft load; inductive coupling means for transferring said electrical output from said shaft and including a first coil assembly adapted for mounting on said shaft and a coupling coil assembly adapted to be supported adjacent said first coil assembly; a decoding assembly associated with said inductive coupling means and load indicator means, said decoding assembly being adapted to decode said electrical output from said inductive coupling means for controlling said load indicator means.

9. Shaft load monitoring apparatus according to claim 8, wherein said load monitoring means includes a strain gauge assembly.

10. Shaft load monitoring apparatus according to claim 8 or claim 9, wherein said first and complementary coil assemblies are formed on metal formers each including a pair of part cylindrical members interconnected by insulation means.

11. An inductive coupling for transmitting electrical signals between a stationary member and a rotatable shaft, including a first former assembly adapted to be supported concentrically about the shaft; a coil assembly supported by said first former; a second former adapted to be supported concentrically and in radially spaced relationship to said first former and a coil assembly supported by said second former.

12. An inductive coupling according to claim 11, wherein said formers are each formed from a pair of part annular metal parts connected together by dielectric connectors to form an annular former.

13. An inductive coupling according to claim 11, wherein at least one of said dielectric connectors is constituted by a hinge assembly.

14. A method of monitoring loads substantially as hereinbefore described.

15. Load monitoring apparatus substantially as hereinbefore described with reference to the accompanying drawings.

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